AD-A192 480 EVALUATION OF A MODIFIED AGA FULL FACE MASK WITH OPEN CIRCUIT/CLOSED CIRC (U) NAVY EXPRRIMENTAL DIVING UNIT PANAMA CITY FL C G PRESSWOOD OCT 87 NEDU-13-87 1/1

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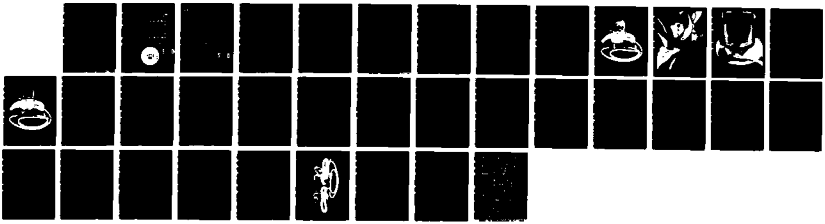

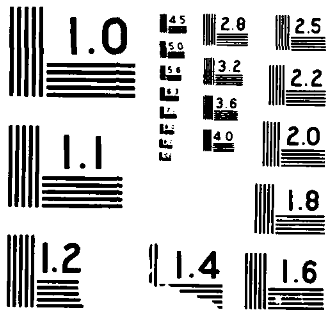
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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 13-87

EVALUATION OF A MODIFIED AGA FULL FACE MASK WITH OPEN CIRCUIT/CLOSED CIRCUIT SWITCHOVER CAPABILITY

CLARK G. PRESSWOOD

OCTOBER 1987

NAVY EXPERIMENTAL DIVING UNIT

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DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407-5001

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AGA	full face mask (FFM)	mouthpiece	NEDU Test Plan 85-26
breathing loop	hydrostatic pressure differential	on/off valve	NEDU Test Plan 86-17
closed circuit	Interspiro	open circuit demand	NAVSEA Task 84-10
Divator II	mask	parallax	viewplate
Draeger LAR V	MK 15 UBA	plunger valve	
faceplate	MK 16 UBA	quick disconnect	

20. ABSTRACT (continue on reverse side if necessary and identify by block number)

The Navy Experimental Diving Unit (NEDU) evaluated a modified AGA Full Face Mask (FFM) with open circuit/closed circuit switchover capability for use with U.S. Navy closed circuit UBA. This FFM, designated Interspiro OC1 FFM, was found to function acceptably with both the MK 15 and Draeger LAR V UBAs, and provides adaptability to the MK 16 UBA should a need be identified. This mask provides an open circuit emergency bailout capability as well as a means of extending dive duration beyond the limitations of the closed circuit UBA.

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Table of Contents

Abbreviations

CmH_2O	centimeters of water pressure (differential)
FFM	full face mask
FSW	feet of seawater
kg.m/ℓ	breathing work in kilogram meters per liter ventilation
kPa	kilopascal
ℓpm	liters per minute (flow rate)
LP	low pressure
MRT	Modified Rhyme Test
NAVSEA	Naval Sea Systems Command
NCSC	Naval Coastal Systems Center
NEDU	Navy Experimental Diving Unit
OSF	NEDU Ocean Simulation Facility
OTS	Ocean Technology Systems
ΔP	differential pressure
PSIG	pounds per square inch gauge
QD	quick disconnect
SCUBA	Self Contained Underwater Breathing Apparatus
SDV	Seal Delivery Vehicle
UBA	Underwater Breathing Apparatus
USN	United States Navy

Abstract

The Navy Experimental Diving Unit (NEDU) evaluated a modified AGA Full Face Mask (FFM) with open circuit/closed circuit switchover capability for use with U.S. Navy closed circuit UBA. This FFM, designated Interspiro OC1 FFM, was found to function acceptably with both the MK 15 and Draeger LAR V UBAs, and provides adaptability to the MK 16 UBA should a need be identified. This mask provides an open circuit emergency bailout capability as well as a means of extending dive duration beyond the limitations of the closed circuit UBA.

KEY WORDS:

AGA
breathing loop
closed circuit
Divator II
Draeger LAR V
faceplate
full face mask (FFM)
hydrostatic pressure differential
Interspiro
mask
MK 15 UBA
MK 16 UBA
mouthpiece
on/off valve
open circuit demand
parallax
plunger valve
quick disconnect
NEDU Test Plan 85-26
NEDU Test Plan 86-17
NAVSEA Task 84-10
viewplate

I. INTRODUCTION. Per NAVSEA Task 84-10, NEDU evaluated a modified AGA Full Face Mask (FFM) with open circuit/closed circuit switchover capability (Figure 1) for use with U.S. Navy closed circuit Underwater Breathing Apparatus (UBA). The modified AGA FFM provided by Interspiro, Lidingo, Sweden, the manufacturer of AGA diving equipment, provides adaptability to the inhalation and exhalation hoses of the MK 15, MK 16, and Draeger LAR V UBAs, while providing the option of switching breathing modes to and from an open circuit SCUBA breathing source.

This report describes the results of manned testing of an initial prototype and manned and unmanned testing of the final configuration of the modified AGA FFM. A background of U.S. Navy development and testing of full face masks designed for closed circuit UBA applications, as well as a discussion of testing of the AGA FFM in various configurations, is provided in the discussion section.

II. FUNCTIONAL DESCRIPTION OF THE MODIFIED AGA FFM. The modified AGA FFM with open circuit/closed circuit switchover capability (Figure 1) provides the same basic AGA mask body as the current MK 15 FFM. A modified manifold provides both open circuit and closed circuit functioning. The closed circuit portion of the manifold and modifications to the open circuit exhaust and open circuit low pressure flex hose provide a means of switching breathing modes during the dive or on the surface.

A. Full Face Mask and Open Circuit Second Stage Regulator. Open circuit breathing gas is supplied to the AGA Divator II second stage regulator at 110-150 psi ambient (135 psi was used during all tests). The regulator is fitted with a double diaphragm safety pressure device which consists of a spring loaded assembly and second diaphragm. This creates a positive pressure to the mask of approximately 2 cm. of water (0.20 kPa) and is intended to prevent mask flooding (prevents water ingress) and provides increased mask comfort and improved breathing performance.

When open circuit gas is provided to the regulator the positive pressure feature is activated by the diver taking his first breath or by activating the positive pressure switch (Figure 2). The mask is held in place by an adjustable spider band. A seal is achieved by the positive pressure acting on a reversed lip around and inside the skirt of the mask. This feature is designed to ensure a comfortable fit and seal without the need to cinch down hard on the spider band during open circuit functioning.

During inhalation, the gas flows from the second stage through two demister ports, across the faceplate and into the oral nasal through two mushroom valves. Figure 3 provides an illustration of the Demister ports and inhalation mushroom valves. Figure 3 is an illustration of the standard AGA Divator II open circuit mask, which shares a common Demister port and mushroom valve configuration with the modified AGA FFM.

During exhalation, gas is expelled to the ambient water through the exhalation valve. Inhalation and exhalation gases pass through separate

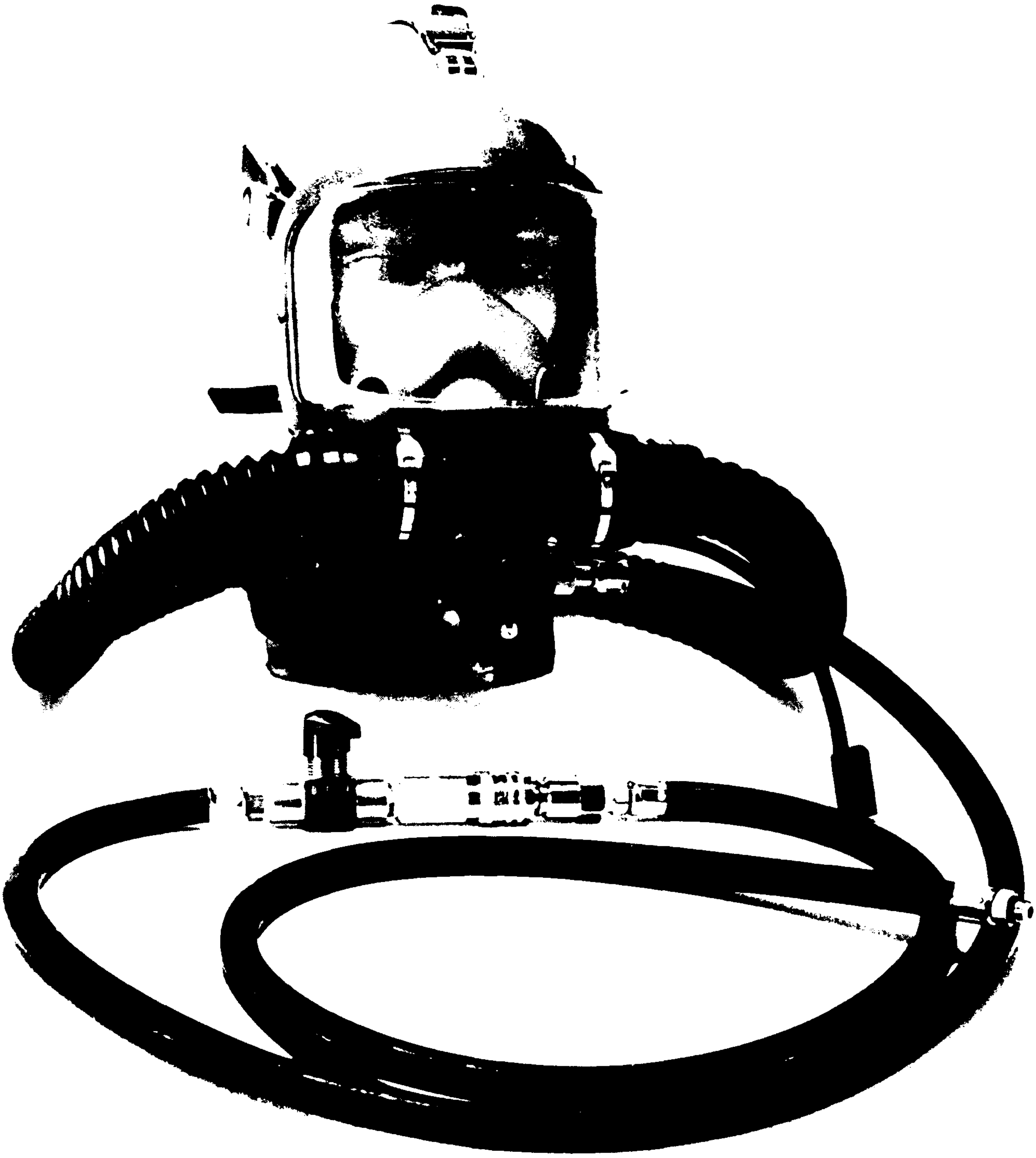

FIGURE 1. MODIFIED AGA FFM IN THE CLOSED CIRCUIT MODE

FIGURE 2. POSITIVE PRESSURE SWITCH, EXHAUST SECURING LEVER AND COMMUNICATIONS SET-UP

FIGURE 3. STANDARD AGA DIVATOR II OPEN CIRCUIT MASK SHOWING DEMISTER PORTS AND INHALATION MUSHROOM VALVES

channels in the second stage to avoid mixing. This separation of gas flow is also designed to minimize the chance of regulator freeze up during diving operations in freezing conditions.

The exhalation valve is specially modified with a lever to secure FFM exhaust when diving in the closed circuit mode (Figure 2). In the open circuit mode the lever extends outward, perpendicular to the exhaust valve cover. In the closed circuit mode the lever must be hand secured shut by pressing the lever flush against the exhaust valve cover. This lever is designed to snap shut, and is located where the purge valve is normally located. A purge valve is not provided in this configuration, and is not considered essential when the positive pressure regulator configuration is used.

B. Gas Supply. Two 38 inch LP hoses (I.D. 7.4 ±.4mm) were provided with the modified AGA FFM for open circuit air supply. These whips are joined together with a quick disconnect (QD) fitting, attached to a ¼ turn Whitey ball valve (attached downstream of QD) to open or secure the open circuit air source. Total length of the flex hose assembly is 82 inches. One end of the assembly provides a fitting to attach to the Divator II second stage regulator. The other end provides a fitting to attach to a standard U.S. First Stage Regulator. A U.S. Divers Royal SL First Stage was used during testing, as this regulator proved to be a superior performer during testing reported by reference 1. Figure 4 provides an illustration of the flex hose assembly in the open circuit mode.

The QD fitting has a non-return valve to prevent gas escaping when released. This fitting allows the diver to detach from the open circuit supply, if required, when diving a closed circuit UBA.

Closed circuit hose fittings are designed for MK 16 UBA size hoses. Adapters are provided for MK 15 UBA and Draeger LAR V UBA hoses.

C. Communications. The modified AGA FFM manifold requires exclusion of the detachable cover plate found on the standard AGA Divator II FFM. This cover plate is normally used to provide communications fitting access to the oral nasal, and can be drilled and fitted with a suitable penetrator, microphone, and connector.

Absence of a cover plate on the modified mask requires that the manifold be specially drilled for installation of a penetrator and connector. The microphone is then attached to the bottom of the nose clearing device. Microphone, penetrator, and connector installation was engineered by Ocean Technology Systems (OTS). A Croise-Hinds Electro Products 51F2F-10 female connector was installed on the mask for evaluation (Figures 2 and 4). This connector provides approximately six inches of wire length, enabling the diver to bring the female fitting within his field of vision when mating or breaking the male and female ends.

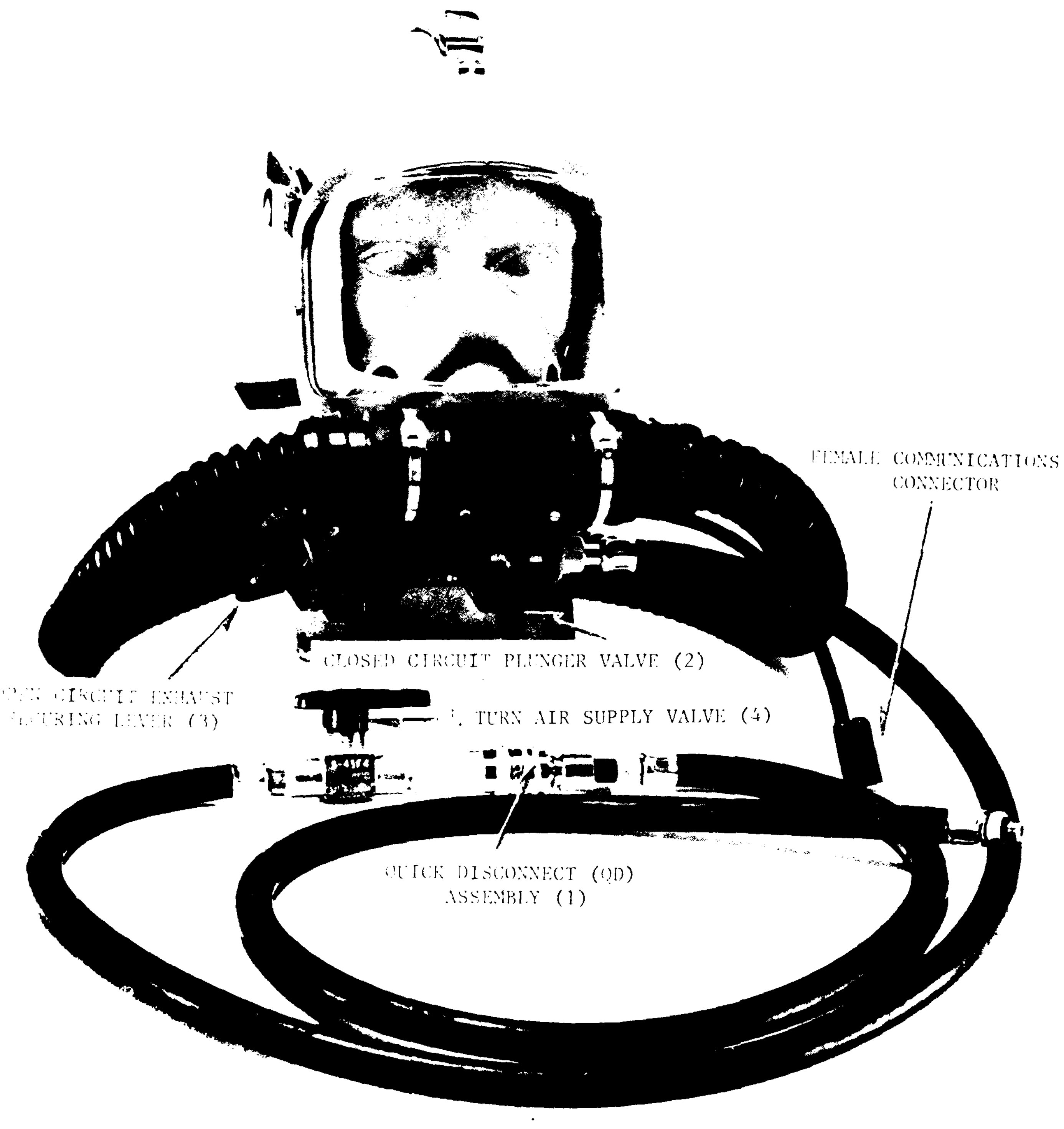

FIGURE 4. MODIFIED AGA FFM IN THE OPEN CIRCUIT MODE

D. FFM Functioning. Open circuit functioning requires that three valves be properly aligned. Figure 4 provides an illustration of the modified AGA FFM in the open circuit mode.

- Ensure the QD is attached (1).

- Rotate the plunger valve to the secured position (2), sealing off the closed circuit breathing loop.

- Pull out the open circuit exhaust valve securing lever (3).

- Open the ¼ turn air supply valve (4).

Prior to donning the mask in the open circuit mode, the positive pressure lever on the open circuit regulator should be secured (snapped shut against mask body). This will prevent regulator free flow when the air supply is opened. Upon donning the mask and inhaling, the lever will snap open, pressurizing the mask to approximately 2 cmH_2O (0.20 kPa), preventing water ingress into the mask if a poor face seal is effected, and providing a high level of breathing performance.

To switch to the closed circuit mode, the three valve alignment switchover process can be accomplished in rapid succession. Figure 1 provides an illustration of the modified AGA FFM in the closed circuit mode.

- Take a breath and hold it.

- Secure ¼ turn air supply valve.

- Secure open circuit exhaust valve (snap shut).

- Rotate plunger valve assembly, opening the closed circuit breathing loop.

In the closed circuit mode, the diver can detach from the open circuit supply, if desired, by unmating the QD. The QD has a push-push action. The male and female ends of the QD assembly must be pushed together, then pushing the locking ring forward will release the assembly. This arrangement prevents accidental disconnect. A one-way valve prevents water from entering the LP hose when unmated underwater. Reconnecting the fitting requires simply pushing the male and female ends together snaptight.

Improper valve sequence when switching breathing modes can be quickly corrected. The most important consideration in proper valve sequence is ensuring the open circuit exhaust valve is open prior to opening the air supply, otherwise a rapid free flow of air will occur in the mask.

III. UNMANNED TESTING. Standardized test procedures were established in reference 2 for the unmanned evaluation of UBAs. These procedures were followed for the testing of the modified AGA FFM. Unmanned breathing

performance testing was conducted in both the open circuit and closed circuit modes. Closed circuit testing was conducted with the MK 15 MOD 0 UBA and the Draeger LAR V UBA.

A. Breathing Performance Data. Table 1 shows the measured and computed results of the modified AGA FFM in the open circuit mode. The AGA Divator II Second Stage Open Circuit Regulator used on this mask is modified with an exhaust securing lever which was left open for the test. The U.S. Divers Royal S/L First Stage regulator was used with an overbottom pressure setting of 135 psi. Air supply pressure was 1000 psi.

Table 2 shows breathing performance data of the standard AGA Divator II open circuit FFM for comparison to Table 1 data. The U.S. Divers Conshelf XIV first stage regulator was used with an overbottom pressure setting of 135 psi. Air supply pressure was 1000 psi.

Table 3 shows breathing performance data of the modified AGA FFM in the closed circuit mode with the MK 15 UBA. Unmanned testing simulated an upright diver attitude. Table 4 shows breathing performance data of the MK 15 UBA with the MK 15 mouthpiece, for comparison with Table 3 data.

Table 5 shows breathing performance data of the modified AGA FFM in the closed circuit mode with the Draeger LAR V UBA. Unmanned testing simulated an upright diver attitude. Table 6 provides performance on data on the Draeger LAR V UBA with the Draeger mouthpiece, for comparison with Table 5 data.

Comparison of Table 1 and Table 2 data shows that the modified AGA FFM in the open circuit mode out performed the standard AGA Divator II open circuit FFM. This is probably due to the use of the U.S. Divers Royal SL First Stage on the modified AGA FFM, whereas the standard AGA Divator II FFM was tested with the U.S. Divers Conshelf XIV First Stage. Both FFMs performed well within standardized NEDU performance goals.

Comparison of Table 3 and Table 4 data shows that the modified AGA FFM installed on the MK 15 UBA out performed the MK 15 UBA with MK 15 mouthpiece. However, comparison of the modified AGA FFM to testing conducted previously on the MK 15 FFM shows that the MK 15 FFM provides slightly superior performance over the modified AGA FFM.

Comparison of Table 5 and Table 6 data shows that the modified AGA FFM installed on the Draeger LAR V UBA out performed the Draeger LAR V UBA with the Draeger mouthpiece.

B. Plunger Valve Leak Test. A gas tight integrity test was conducted on the modified AGA FFM to determine the effectiveness of the switchover assembly (plunger valve) to seal off the closed circuit mode from the open circuit mode under conditions of hydrostatic pressure.

The plunger valve seat was subjected to a leak test by installing a plug in the end of the exhalation breathing hose and installing a manometer and

TABLE 1. OPEN CIRCUIT BREATHING LOOP DATA ANALYSIS SHEET

EQUIPMENT TESTED: Modified AGA FFM in Open Circuit Mode with U.S. Divers Royal S/L First Stage Regulator

BREATHING GAS: Air

OVERBOTTOM SETTING: 135 psig

CONSOLE PRESSURE: 1000 psig

RMV (LPM)	DATA	DEPTH (FSW) 0	33	66	99	132	150	165	198
22.5	EXH	3.28	4.15	3.04	3.04	4.08	4.29	3.77	3.94
	INH	-3.84	-3.94	-3.35	-3.73	-3.60	-3.60	-3.94	-3.84
	WORK	.0218	.0292	.0371	.0409	.0480	.0478	.0485	.0493
40.0	EXH	3.73	3.77	5.17	4.36	5.38	6.42	4.12	7.09
	INH	-4.33	-5.38	-3.84	-6.00	-5.10	-4.89	-7.54	-5.79
	WORK	.0326	.0435	.0531	.0616	.0665	.0718	.0749	.0820
62.5	EXH	5.44	6.77	7.71	9.32	11.45	13.86	14.83	17.45
	INH	-3.60	-5.72	-5.79	-5.72	-7.75	-9.98	-14.52	-26.56
	WORK	.0437	.0602	.0790	.0966	.1248	.1489	.1782	.2576
75.0	EXH	6.00	8.13	9.08	13.02	14.52	15.43	19.51	0.00
	INH	-7.02	-5.34	-6.56	-8.24	-22.20	-36.09	-46.35	0.00
	WORK	.0496	.0722	.0976	.1391	.2208	.3006	.3649	0.0000
90.0	EXH	4.99	10.72	11.20	19.20	0.00	0.00	0.00	0.00
	INH	-6.49	-3.84	-10.40	-20.63	0.00	0.00	0.00	0.00
	WORK	.0557	.0885	.1387	.2371	0.0000	0.0000	0.0000	0.0000

EXH = Exhalation effort in centimeters H_2O

INH = Inhalation effort in centimeters H_2O

WORK = Work of breathing in kg·m/ℓ

<u>NOTE</u>: NEDU performance goal for work is 0.18 kg·m/ℓ (1.8 J/ℓ) at 132 FSW and 62.5 RMV (*NEDU Report 3-81*)

TABLE 2. OPEN CIRCUIT BREATHING LOOP DATA ANALYSIS SHEET

EQUIPMENT TESTED: Standard AGA Divator II FFM with U.S. Divers Conshelf XIV First Stage Regulator

BREATHING GAS: Air

OVERBOTTOM SETTING 135 psig

CONSOLE PRESSURE: 1000 psig

RMV (LPM)	DATA	DEPTH (FSW) 0	33	66	99	132	165	198	300
22.5	EXH	2.39	3.13	3.91	3.59	4.43	4.68	3.69	5.00
	INH	-2.92	-5.14	-2.67	-3.41	-2.96	-2.88	-4.12	-4.05
	WORK	.0334	.0358	.0451	.0459	.0480	.0501	.0524	.0622
40.0	EXH	3.24	4.82	5.14	5.49	6.72	7.32	7.74	8.69
	INH	-2.67	-3.27	-3.73	-4.33	-3.52	-4.15	-5.77	-6.75
	WORK	.0370	.0482	.0572	.0644	.0707	.0769	.0885	.1095
62.5	EXH	6.54	6.33	8.76	7.25	10.31	11.86	11.86	0.00
	INH	-2.64	-4.43	-3.94	-7.56	-6.02	-7.85	-16.08	0.00
	WORK	.0483	.0624	.0836	.0992	.1131	.1336	.1726	0.0000
75.0	EXH	7.11	7.95	8.02	12.70	11.36	14.85	16.15	0.00
	INH	-2.99	-4.43	-6.23	-5.63	-12.28	-28.95	-55.13	0.00
	WORK	.0560	.0764	.0983	.1240	.1564	.2553	.4053	0.0000
90.0	EXH	7.74	10.48	12.81	15.41	15.41	0.00	0.00	0.00
	INH	-8.87	-4.12	-5.17	-12.28	-39.89	0.00	0.00	0.00
	WORK	.0630	.0919	.1240	.1761	.3186	0.0000	0.0000	0.0000

EXH = Exhalation effort in centimeters H_2O

INH = Inhalation effort in centimeters H_2O

WORK = Work of breathing in kg·m/ℓ

NOTE: NEDU performance goal for work is 0.18 kg·m/ℓ (1.8 J/ℓ) at 132 FSW and 62.5 RMV (NEDU Report 3-81)

TABLE 3. CLOSED CIRCUIT BREATHING LOOP DATA ANALYSIS SHEET

EQUIPMENT TESTED: Modified AGA FFM with MK 15 UBA

BREATHING GAS: Air

GAS SUPPLY PRESSURE: 1000 psig

RMV (LPM)	DATA	DEPTH (FSW) 0	33	66	99	132	150	165	198
22.5	PEAK TO PEAK	8.21	8.60	8.70	10.22	11.26	12.01	12.35	12.88
	WORK	.0267	.0345	.0400	.0436	.0550	.0587	.0624	.0677
40.0	PEAK TO PEAK	10.94	12.53	13.88	16.12	18.61	20.47	21.44	23.37
	WORK	.0388	.0615	.0804	.0980	.1134	.1229	.1304	.1465
62.5	PEAK TO PEAK	14.53	20.09	26.20	31.41	35.79	38.22	40.91	44.12
	WORK	.0688	.1200	.1645	.2012	.2353	.2493	.2657	.2950
75.0	PEAK TO PEAK	16.26	24.55	34.49	41.53	47.68	48.53	48.53	58.82
	WORK	.0881	.1584	.2198	.2705	.3130	.3226	.3226	.3851
90.0	PEAK TO PEAK	21.13	33.93	45.02	52.47	59.34	0.00	0.00	0.00
	WORK	.1139	.2044	.2841	.3451	.3834	0.0000	0.0000	0.0000

EXH = Exhalation effort in centimeters H_2O

INH = Inhalation effort in centimeters H_2O

WORK = Work of breathing in kg·m/ℓ

TABLE 4. CLOSED CIRCUIT BREATHING LOOP DATA ANALYSIS SHEET

EQUIPMENT TESTED: MK 15 UBA with MK 15 Mouthpiece Normal Configuration

BREATHING GAS: Air

GAS SUPPLY PRESSURE: 1000 psig

RMV (LPM)	DATA	DEPTH (FSW) 0	33	66	99	132	165	198	300
22.5	PEAK TO PEAK	8.70	15.24	15.77	18.36	21.54	23.38	23.42	0.00
	WORK	.0428	.0573	.0665	.0766	.0849	.0956	.1042	0.0000
40.0	PEAK TO PEAK	14.65	23.59	25.57	29.25	32.53	36.93	38.01	0.00
	WORK	.0785	.1016	.1291	.1577	.1831	.2118	.2380	0.0000
62.5	PEAK TO PEAK	23.73	33.14	39.83	48.38	57.68	67.05	76.79	0.00
	WORK	.1376	.1860	.2547	.3158	.3836	.4486	.5139	0.0000
75.0	PEAK TO PEAK	28.72	39.54	53.40	66.00	79.75	0.00	0.00	0.00
	WORK	.1750	.2481	.3468	.4387	.5368	0.0000	0.0000	0.0000
90.0	PEAK TO PEAK	32.97	50.51	69.75	82.01	0.00	0.00	0.00	0.00
	WORK	.1878	.3226	.4581	.5813	0.0000	0.0000	0.0000	0.0000

EXH = Exhalation effort in centimeters H_2O

INH = Inhalation effort in centimeters H_2O

WORK = Work of breathing in kg·m/ℓ

TABLE 5. CLOSED CIRCUIT BREATHING LOOP DATA ANALYSIS SHEET

EQUIPMENT TESTED: Modified AGA FFM with Draeger LAR V UBA

BREATHING GAS: Air

AIR SUPPLY PRESSURE: 1000 psig

RMV (LPM)	DATA	DEPTH (FSW) 0	25	50
22.5	PEAK TO PEAK	14.21	25.79	24.79
	WORK	.0361	.0475	.0554
40.0	PEAK TO PEAK	28.63	32.47	32.47
	WORK	.0474	.0936	.0936
62.5	PEAK TO PEAK	32.68	39.01	41.99
	WORK	.0740	.1244	.1665
75.0	PEAK TO PEAK	34.95	40.50	45.33
	WORK	.0914	.1556	.2157
90.0	PEAK TO PEAK	38.79	46.89	53.78
	WORK	.1163	.1985	.2771

EXH = Exhalation effort in centimeters H_2O

INH = Inhalation effort in centimeters H_2O

WORK = Wo-k of breathing in kg·m/ℓ

TABLE 6. CLOSED CIRCUIT BREATHING LOOP DATA ANALYSIS SHEET

EQUIPMENT TESTED: Draeger LAR V UBA with Draeger Mouthpiece

BREATHING GAS: Air

AIR SUPPLY PRESSURE: 1000 psig

RMV (LPM)	DATA	DEPTH (FSW) 0	25	50
22.5	PEAK TO PEAK	11.87	25.37	22.74
	WORK	.0421	.0578	.0686
40.0	PEAK TO PEAK	29.55	32.47	35.38
	WORK	.0702	.1054	.1335
62.5	PEAK TO PEAK	35.17	42.42	45.96
	WORK	.1148	.1832	.2408
75.0	PEAK TO PEAK	38.02	45.12	46.40
	WORK	.1437	.2370	.3139
90.0	PEAK TO PEAK	42.56	54.07	62.17
	WORK	.1801	.2986	.3972

EXH = Exhalation effort in centimeters H_2O

INH = Inhalation effort in centimeters H_2O

WORK = Work of breathing in kg·m/ℓ

pressurizing tube on the inhalation hose. The manometer used was designed to measure pressure in inches of water. The FFM plunger valve was switched to the closed circuit mode, and the inhalation hose was pressurized with air to a pressure of 1½ inches of water. The FFM was submerged in fresh water during the test, and the plunger valve orifice within the FFM was observed for bubble leakage for a period of 2 hours. No leakage or loss of hose pressure occurred.

IV. MANNED TESTING

Manned testing of the modified AGA FFM comprised primarily of test dives in the NEDU Test Pool using various diver-subjects. However, the initial prototype of the mask which utilized a rotator barrel valve (as opposed to a plunger valve) was also submitted for a fleet evaluation at SDV Team ONE. All divers were trained in the MK 15 FFM, therefore training in the modified AGA FFM was simple, and was conducted by NEDU personnel in a pool environment. Diver training was followed by SDV open water swims. The evaluation focused on ease of switchover functioning, SDV compatibility, communications testing, and diver receptivity to the new mask. Seven SDV Team personnel participated in the evaluation.

A. Fleet Evaluation

1. LP Hose, ¼ Turn Air Supply Valve, and QD Fitting. Diver opinions varied on preferred LP hose length and optimum location of the QD and ¼ turn air supply valve. In the interest of simplicity, some divers preferred not to have a ¼ turn valve. Air supply would preferably be opened or secured at the air cylinder valve.

The ¼ turn air supply valve was included to provide the capability of rapidly opening or securing open circuit supply. The air cylinder valve is comparatively more difficult to turn (especially with cold hands), requires greater valve handle rotation to activate or deactivate pressure, and may not be as accessible to the diver in some cases. Operational experience may dictate the optimum configuration.

The length of the LP hose was in excess of 8 feet during the fleet evaluation. It was assumed that this would be too long, but the hose length could be configured to diver preference following the evaluation. During the evaluation, it was determined that an approximate total length of 6 feet would be the optimum configuration for most anticipated applications. The AGA Divator II regulator is a high performing regulator even with the long hose lengths and interconnecting ¼ turn valve and QD.

The QD fitting is located approximately 3 feet upstream from the demand regulator. QD location preference on the LP hose varied among the divers who participated in the evaluation, however most agreed that the optimum location would be approximately 6 inches upstream of the demand regulator. This would allow the diver to bring the QD fitting within the diver's field of view when mating or unmating the fitting (this is also true of the new 6 inch communications connector installed in the mask), and would leave only 6 inches amount of LP hose length hanging from the mask when the fitting was unmated.

The ¼ turn air supply valve is located downstream of the QD fitting. The preferred location is upstream of the QD, so that this valve will not be connected to the mask when the QD is unmated.

2. FFM Functioning. Functioning of the modified AGA FFM proved to be easy to learn and easy to conduct, even in a dark, confined environment. In one instance a diver surfaced and complained of a slight leak of closed circuit gas from the open circuit regulator exhaust valve. This occurred while diving in the closed circuit mode. The diver was instructed to cycle the open circuit exhaust securing lever (cycle open and closed) to re-seat the diaphragm. This proved to alleviate the problem.

One day of pool dives and three days of open water bay dives were completed with seven fleet personnel and two NEDU divers. Bay temperature was approximately 62°F. The only complaint which could not be immediately corrected was mask fogging. All divers utilizing the modified AGA FFM with the MK 15 UBA were accompanied by a swim buddy utilizing the current MK 15 FFM. Fogging of the modified FFM proved to be severe compared to the MK 15 FFM. This is because the MK 15 FFM faceplates have been treated with a permanently bonded anti-fog coating provided by Exxene Corp., Corpus Christi, Texas. Application of a liquid anti-fog solution over the permanently bonded coating prior to each dive is still required to prevent excessive fogging. If the mask is ever removed on the surface during the diving evolution, liquid anti-fog solution should be re-applied. Some fogging will still occur even when these precautions are taken.

Examination of the faceplates which had been treated with the permanently bonded solution revealed some patchy degradation of the anti-fog coating on masks which had been in service for several years. Some of the older masks which did not show actual wearing off of the coating did show the beginning of degradation in the form of rainbow steaks across the lens. These streaks did not compromise vision, but are an indication that reapplication of the permanent coating may be warranted periodically. The modified AGA FFM should receive a similar permanent bond anti-fog coating.

Upon conclusion of the fleet evaluation a test of closed circuit rotator valve integrity was conducted by filling the oral nasal cavity with water and exerting a slight pressure on the MK 15 UBA diaphragm. Slight bubbling was noticeable, indicating a slow leak of closed circuit gas into the FFM during open circuit functioning. This resulted in the mask being returned to the manufacturer for redesign. A new prototype was then provided to NEDU in the same configuration as the previous prototype, except that the closed circuit rotator valve was replaced with a new design plunger valve, and a shortened (82-inch) flex hose assembly was provided. Testing of the new prototype was continued in the NEDU Test Pool. This new prototype proved to be the final configuration of the modified AGA FFM.

3. Communications Test. It was assumed that the modified AGA FFM would provide improved communications functioning because the MK 15 UBA microphone (Ocean Technology Systems) is configured substantially closer to

the diver's mouth compared to the current MK 15 FFM. Diver to diver communications effectiveness tests were conducted in a static, submerged (10 FSW) SDV environment (front and rear compartments) using the Modified Rhyme Test (MRT). One series of tests was conducted with a diver using the current MK 15 FFM reading from the word list. Another series of tests was conducted with a diver using the modified AGA FFM reading from the word list (closed circuit mode). During both tests three divers recorded answers from 100 words which were graded. Scores are as follows:

MK 15 FFM

Diver 1:	86%	front compartment
Diver 2:	78%	rear compartment
Diver 3:	90%	rear compartment

MODIFIED AGA FFM

Diver 1:	94%	front compartment
Diver 2:	93%	rear compartment
Diver 3:	88%	rear compartment

Another 100 word test was conducted with the word list reader utilizing the modified AGA FFM in the open circuit mode, with the following results:

Diver 1:	82%	front compartment
Diver 2:	82%	rear compartment
Diver 3:	78%	rear compartment

B. NEDU Test Pool Evaluation. The final version of the modified AGA FFM with the new design closed circuit plunger valve was submitted to a manned evaluation in the NEDU Test Pool. Five diver-subjects accumulated a total bottom time of 12.5 hours on the mask in 50°F water temperature with no disfunctions. Three of the diver-subjects had limited experience with the MK 15 UBA or the AGA FFM in any configuration, but all were able to quickly learn how to switch functions with the mask in rapid fashion. Additional dives were also conducted by NEDU personnel with the Draeger LAR V UBA fitted to the modified AGA FFM. This mask proved to be easily adaptable to the Draeger LAR V UBA.

One hour MK 15 UBA dives were conducted in 50°F water temperature wearing a DUI TLS fabric dry suit with bare hands. When hands chilled to the point of significant loss of manual dexterity, a 3/16 inch 5 finger wet suit glove covered with a three fingered 3/16 inch wet suit glove was donned to encumber the divers cold hands. Switching breathing modes back and forth from open to closed circuit, including detaching and reattaching the QD fitting was accomplished with ease.

V. DISCUSSION

A. Historical Development of Closed Circuit FFM. FFM application to closed circuit UBA provides the advantage of communications capability,

thermal protection in the facial area, and increased diver survivability in the event unconsciousness occurs due to hypoxia, hypercapnia, or oxygen toxicity (e.g. FFM may prevent drowning prior to diver recovery and resuscitation efforts). FFM use may also improve UBA breathing performance over a standard mouthpiece in some cases. The inherent advantages of FFM use with closed circuit UBA has resulted in a considerable historical development effort on the part of the U.S. Navy, as discussed in the following paragraphs. This review is provided in order to give the reader a perspective of associated problems with closed circuit FFM applications, as well as an understanding of the evolution of the current system.

1. Market Survey for Closed Circuit FFM. A market survey and evaluation project for a suitable FFM for MK 15 UBA (then called Swimmer Life Support System - SLSS MK 1) application was conducted from 1972 to 1977, and included consideration of numerous FFM types available commercially and within the USN diving equipment inventory. This included the MK 11 Facemask, Widolf FFM, KMB-10, Scott, AGA and U.S. Divers Model 5205-00 MK 1 professional with two hose regulator adapter kit and retractable mouthpiece. It was also proposed to test a mock up of the MK 11 MOD 0 Dry Helmet in order to evaluate the dry helmet concept as a means of containing the basic problem of mask over-pressurization which occurs in an upright diver attitude resulting from the hydrostatic pressure differential between the FFM and closed circuit breathing loop. Hydrostatic pressure build up within the MK 11 UBA was believed to be of the same order of magnitude as that of the MK 15 UBA. It was felt that the MK 11 mask face seal (a hydroseal with adjustable pressure) would reduce offgassing due to its improved seal design. However, this mask proved to be uncomfortable and a complete evaluation was not conducted.

2. TRI-SCUBA FFM. A prototype AGA FFM, called the TRI-SCUBA mask, was also evaluated. This mask was originally conceived to allow the diver to change breathing modes (open circuit/closed circuit switchover) at will, while submerged with minimal introduction of water in the mask. Manned testing at NEDU established that changing from one breathing mode to another while submerged could be accomplished but not with adequate consistency. The diver had to hold his breath while changing the detachable manifolds on the mask underwater, and excessive water entered the mask during the switchover process. Mask fogging also proved to be a problem.

Following this evaluation it was determined that an AGA FFM modified for closed circuit use (eliminating the open circuit option provided by the TRI-SCUBA mask) was the optimum mask available for closed circuit UBA application. This resulted in development and approval of the current MK 15 FFM, which was the first USN use of the AGA FFM body.

3. MK 15 FFM. Development of the current MK 15 FFM was initiated by the Naval Coastal Systems Center (NCSC) in 1973. Following development and testing, this mask was manufactured by Rexnord, Inc., Malvern, Pa., the manufacturer of the MK 15 and MK 16 UBA. NEDU testing of the MK 15 FFM was conducted in 1978 and 1979 as reported by references 3 and 4. This mask proved to provide an acceptable communications capability, additional thermal protection in the facial area, and reduced work of breathing with the MK 15 UBA compared to the MK 15 UBA mouthbit (a Scott mouthpiece).

An exhaustive series of manned dives in the NEDU Ocean Simulation Facility (OSF) and open water dives, including SDV dives, were conducted with the MK 15 FFM to demonstrate its suitability and effectiveness. After 618.5 hours of cumulative bottom time with no mission aborts attributable to the mask, it was determined that the mask met or exceeded all threshold criteria and established goals except that testing in maximum water temperature of 93°F was not conducted, and attainment of an intelligibility score of 90% on the Modified Rhyme Test (MRT) was not accomplished due to problems associated with the SDV communications system rather than the FFM.

a. Mask Fogging. FFM fogging was a key problem that occurred during the evaluation, and resulted in the termination of one phase of testing to allow for investigation of the problem. A special series of dives in the NEDU Test Pool were conducted in an effort to solve the fogging problem, eventually accumulating 117 hours of bottom time in the evaluation of products acquired as a result of a market search for commercially available anti-fog solutions. A product called "Final Solution" produced by Exxene Corp., Corpus Christi, Texas, was found to be far superior to other products tested. This product washed off, however, when the mask was flooded. The manufacturer indicated that the anti-fog compound could be permanently bonded to the FFM lens. A chemical composite consisting of a permanently bonded coating, applied by a chemist, and a wipe-on additive applied before each dive proved to provide some protection against lens fogging. This anti-fog material was tested for toxic off gassing and found to be within acceptable limits.

b. Mask Comfort and Optical Distortion. Problems relating to mask comfort, breathing resistance (static pressure loading), and side view distortion were reported on the diver comment sheets during the MK 15 FFM evaluation. However, mask discomfort and breathing resistance were found to decline as divers gained experience and learned to adjust the MK 15 harness to conform to body attitude. The amount of adjustment varied depending on the individual build of the diver. Optical distortion (parallax) was eliminated by etching the side viewplate on both sides. Following approval of the MK 15 FFM, this mask experienced several years of fleet use, resulting in continued complaints of mask discomfort and breathing resistance, fogging, and restricted peripheral vision. These problems will be discussed later in this section.

4. AGA FFM

a. U. S. Navy Use. The AGA FFM was originally designed as a fire fighting mask, and received wide acceptance in commercial and sport diving markets after being modified for diving use. Following modifications of the AGA mask to closed circuit MK 15 UBA application in 1979, various open circuit variations of this mask have been submitted to extensive testing at NEDU in both the open circuit SCUBA and umbilical supplied modes as reported by references 5 through 12.

Reference 5 evaluated the AGA Divator 324 FFM for inclusion in NAVSEAINST 10560.2 (Diving Equipment Authorized for Navy Use). It was found that this FFM met all requirements for use with open circuit SCUBA and any authorized

first stage SCUBA regulator. Reference 6 evaluated the AGA Divator 324 FFM with the Efcom Wireless Underwater Communicator. Reference 7 provides a 1983 evaluation of the AGA 324 mask, already approved for open circuit SCUBA use, but modified for an umbilical supply. Reference 8 evaluated an AGA FFM with a new design open circuit SCUBA regulator, which is now standard equipment on the AGA Divator II FFM. The new regulator provides a purge button and an externally mounted lever system to automatically initiate positive overbottom pressure within the mask. This device was designed to improve comfort, breathing performance, and prevent mask flood out. An improved demand valve was also added.

References 9, 10, and 11 evaluated the AGA Spiro Divator II lightweight diving system, which is now in development as a replacement to the Jack Browne mask for enclosed space diving. During testing reported by reference 11, the AGA Divator II lightweight umbilical supplied diving system was found to provide superior breathing performance over the MK 1 MOD 0 Band Mask, Widolf FFM, and a Ryan 26 prototype (EXO-26) FFM. Reference 12 evaluated the AGA Divator II FFM with the OTS Underwater Communications Systems. Reference 1 found the Divator II Second Stage Open Circuit SCUBA Regulator and positive pressure Divator II FFM to be superior performers (Category "A") when compared to 51 commercially available SCUBA Regulators, when used with the U.S. Divers Royal S/L First Stage Regulator.

b. Field of Vision. A disadvantage to the AGA FFM is the limited peripheral vision provided by the faceplate. A more detailed discussion of this matter is provided in reference 9. A reduction in visual field compared to normal unobstructed vision is especially marked in the lateral peripheral area (e.g. 210° and 330° radians) where the visual field is reduced by approximately two-thirds. This occurs due to the requirement to etch the side viewplates of the AGA faceplate to prevent visual distortion or parallax which has been noted to be unsettling to some divers. Parallax has been reported on the unetched AGA faceplate. Parallax is the apparent displacement of an observed object due to the difference between two points of view (between the front viewplate and side viewplates of the AGA visor or faceplate), and has been a particular complaint of divers who were unfamiliar with the mask. As diver familiarity and experience increases, it is probable that complaints of parallax would diminish considerably.

The original prototype of the MK 15 FFM included clear (un-etched) side viewplates. When the final version of the mask was delivered for fleet use, the side viewplates had been etched by the manufacturer to prevent parallax from occurring. Etching of the side viewplates was unsolicited by the U. S. Navy, but was conducted by the manufacturer due to concerns of mask safety. Leaving the side viewplate clear would have allowed divers to black out the side viewplate if they were unable to adjust to parallax. Etching does not allow this option and reduces peripheral vision. However, it has resulted in a mask which is free from parallax. Etched side viewplates are now standard on all versions of the AGA FFM.

An additional problem sometimes experienced with side viewplates is light reflection through the side viewplate, which can cast an image on the inside

of the front viewplate. This can have the tendency of obstructing vision, and could possibly result in vertigo to some divers. This problem may be less pronounced when diving in areas of reduced light.

Further in-depth testing of an unetched lens may be warranted, however the manufacturer has developed a low volume faceplate to improve peripheral vision, eliminate optical distortion, and reduce mask bouyancy, possibly reducing jaw fatigue. The low volume faceplate will be the subject of a separate evaluation.

The AGA FFM body in various configurations has been found to be suitable for numerous USN applications, particularly in the open circuit mode. Numerous evaluations have found the AGA FFM to be a very comfortable, easy to use system. However, the MK 15 FFM has been the subject of complaints of mask discomfort and breathing resistance due to the hydrostatic pressure differential which occurs within the closed circuit breathing loop, which would not normally occur during open circuit functioning.

5. Hydrostatic Pressure Within Closed Circuit FFM. Hydrostatic pressure differential can occur between the closed circuit UBA breathing loop and the FFM, creating breathing resistance during either exhalation or inhalation depending upon diver attitude. Figure 5 provides a schematic demonstrating the effects of changes in diver attitude on mask static loading pressure. For a diver in a prone swimming position, the pressure differential is not normally pronounced. However, when the diver assumes an upright position, breathing gas from the UBA breathing diaphragm seeks the shallower depth of the FFM. This can cause excessive pressurization of the mask which can result in gas leaks through the mask seal. To prevent the loss of closed circuit breathing gas from the FFM, secure tightening of the FFM spider straps is often required, which can result in mask discomfort, headaches, and jaw fatigue, especially during extended duration dives.

The end result of the hydrostatic pressure differential problem in an upright diver attitude is that inhalation becomes relatively effortless, whereas exhalation is more difficult due to the requirement to force breathing gas down into the UBA canister. In a head down diver attitude, the hydrostatic pressure differential reverses, so that exhalation resistance is low, but inhalation resistance is high. This can force the mask tight against the divers face, resulting in some degree of discomfort.

For a seated, or upright diver utilizing the MK 15 UBA, the center of pressure of the diaphragm can be as much as 8 to 10 inches below the center of pressure of the FFM if the UBA is not jocked high on the divers back, causing sufficient internal positive pressure to break the face seal. Seated diver pressure differentials of up to 0.4 psi can develop between the interior and exterior of the mask. Resulting gas leaks can cause rapid diluent gas depletion, possibly decreasing UBA duration time, and creating an acoustic signature and bubble detection.

The AGA mask was designed to seal adequately against overpressure of 10-15 cmH_2O in demand UBAs. This mask was designed for a balanced breathing

P = MASK STATIC LOADING PRESSURE

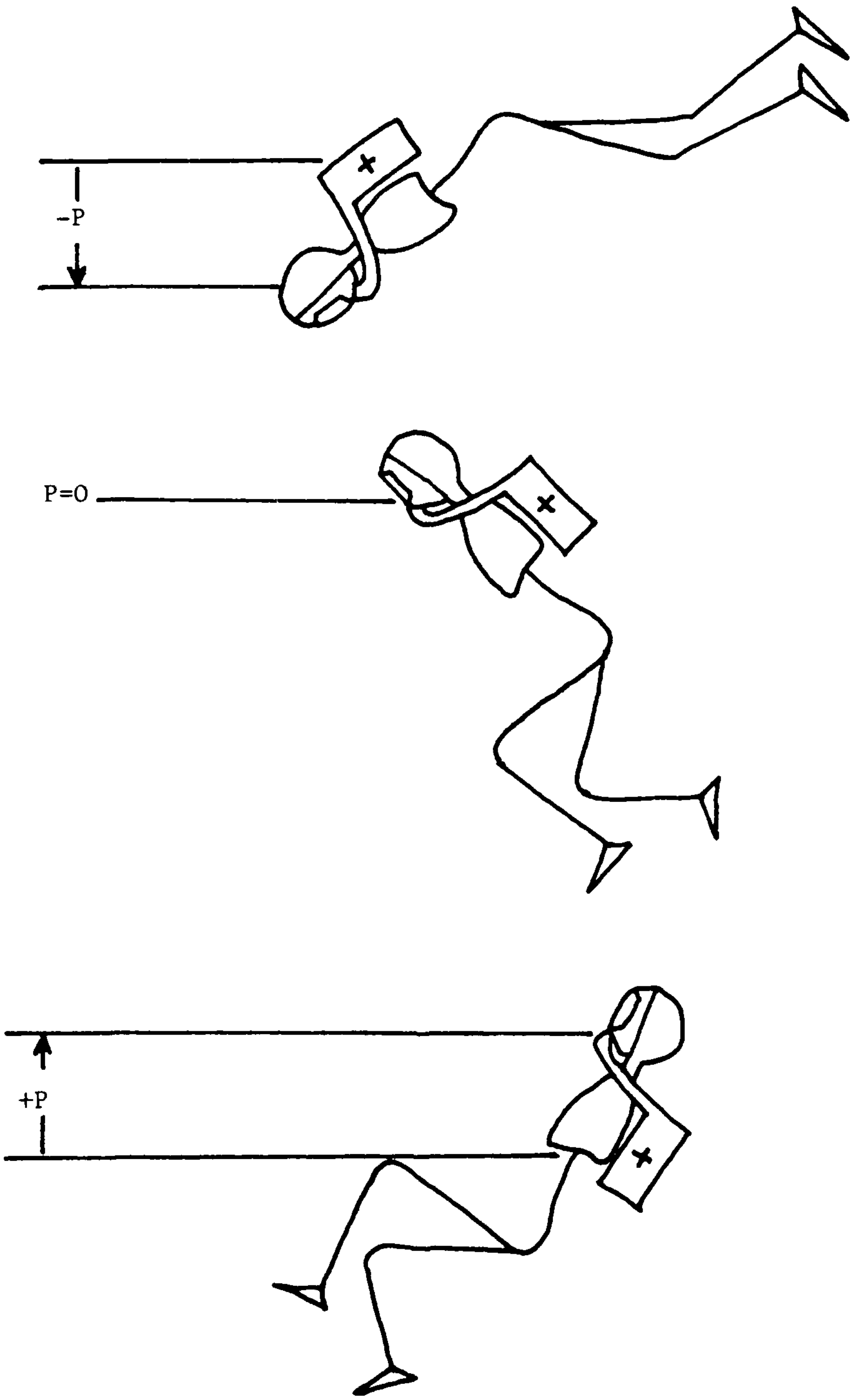

FIGURE 5: SCHEMATIC DEMONSTRATING EFFECT
OF CHANGES IN DIVER ATTITUDE
ON MASK STATIC LOADING PRESSURE

circuit apparatus, and has been incorporated into the AGA ACSC UBA developed for the Swedish Navy. This UBA has a balanced breathing bag which reportedly keeps mask overpressures within design limits in any diver orientation. The MK 15 UBA can develop static pressures up to 30 cmH_2O in an upright diver attitude.

In order to counteract the FFM overpressurization and offgassing problem, MK 15 divers have learned to jock the UBA as high as possible on the divers back. This resulted in a proposed modification to the original MK 15 UBA harness (lowering the shoulder harness connecting point on the UBA) to allow UBA jocking high on the divers back. High jocking reduces the pressure differential between the FFM and UBA breathing loop. Although this problem can occur in varying degrees with any closed circuit UBA, including chest worn units, the pressure differential is more easily contained to prevent offgassing when a mouthpiece is used, and tight jocking of a FFM is not required. Testing shows, however, that the MK 15 FFM provides reduced overall work of breathing when compared to the MK 15 mouthpiece, apparently due to the larger orifice sides and superior one way valves used in the MK 15 FFM.

MK 15 FFM discomfort due to hydrostatic pressures differential has been attributed to the AGA FFM (face seal) design. However this is more a function of UBA design. Closed circuit UBAs designed for FFM use should locate the UBA breathing loop as close as possible to the divers head or neck area so that pressure differentials will be reduced, especially when a predominantly upright diver attitude is anticipated. If this is not accomplished, then a FFM with exceptional face seal design which can accommodate tight jocking, or otherwise provide secure face seal integrity under conditions of excessive internal pressure should be acquired or developed.

6. Current Testing of Alternative Closed Circuit FFMs. Three commercially available FFMs which demonstrated possible application to the MK 15 and Draeger LAR V UBAs were evaluated at NEDU in 1985 in order to identify a possible candidate for further testing. A modified Widolf FFM, a closed circuit Draeger FFM, and a modified AGA FFM were submitted to a manned evaluation in the NEDU Test Pool. An unmanned evaluation of the Widolf FFM modified for closed circuit (MK 15 UBA) use is reported by reference 13. It provides a soft face seal designed to provide more comfortable wear when jocked tightly. A modification for open circuit/closed circuit switchover capability was also provided on the latest Widolf FFM prototype. The Draeger FFM has been commercially modified for use with different Draeger UBA. The modified AGA FFM contains a manifold which includes an open circuit/closed circuit switchover capability.

The modified Widolf and Draeger FFMs were not found to provide an effective face seal when compared to the modified AGA FFM. A human factors evaluation of the Widolf FFM is provided by reference 14. Therefore further testing was terminated on the Widolf and Draeger Masks, and testing continued on the modified AGA mask.

B. Modified AGA FFM

1. Static Pressure Loading, Mask Fogging, and Peripheral Vision. The problems of static pressure loading, mask fogging, and reduced peripheral vision experienced with the current MK 15 FFM have been the subject of numerous evaluations at NEDU. These problems will also be experienced with the modified AGA FFM. FFM static pressure loading is a function of UBA design. No lightweight FFM tested at NEDU has been found to provide superior sealing over the AGA design. UBA jocking will tend to reduce static pressure in an upright (vertical) diver attitude, and is the only feasible method of reducing static pressure until an improved UBA or FFM becomes available.

The permanent bond anti-fog coating applied by Exxene Corp. is the most effective preventative when an effective liquid coating is applied prior to each dive. A new liquid anti-fog spray "Fog-Off" was evaluated during testing with promising results, however exceptionally long duration dives in cold temperatures were not conducted in the closed circuit mode, and further testing of anti-fog materials is warranted. A new low volume faceplate provided by Interspiro may provide improved peripheral vision, and will be reported on separately.

The open circuit switchover option provided by the modified AGA FFM will provide an additional capability not enjoyed with the MK 15 FFM, including a means of rapid bail out in the event of closed circuit UBA malfunction, and a means of extending mission duration beyond the limits of the closed circuit UBA. Open circuit breathing, when feasible, generally provides a more comfortable mask seal and reduced breathing work. The similarities of the modified AGA and MK 15 FFMs provides commonality of training. Figure 6 provides a side by side illustration of the MK 15 FFM and AGA FFM.

The modified AGA FFM breathing hose fittings are designed for MK 16 UBA size hoses. This FFM is suitable for use with the MK 16 UBA should a requirement be identified for certain applications. Adapters are provided for MK 15 and Draeger LAR V UBA breathing hoses connection. This FFM will provide suitable application for the Draeger LAR V as well as the MK 15 UBA. Application of a FFM to the LAR V was foreseen by reference 15. An evaluation of the purge requirements was made, and use of purge procedure "C" with a FFM was recommended. Exhaling to sea during the purge is accomplished by securing the closed circuit plunger valve and exhaling through the open circuit exhaust valve.

The LP hose configuration has been the subject of variable preferences. Any desired configuration can be provided by the manufacturer. The optimum hose configuration based on fleet testing and operator input is listed in the next section.

VI. CONCLUSIONS

The modified AGA FFM, hereafter to be referred to as the Interspiro OC1 FFM, offers a suitable open circuit switchover capability with the same mask

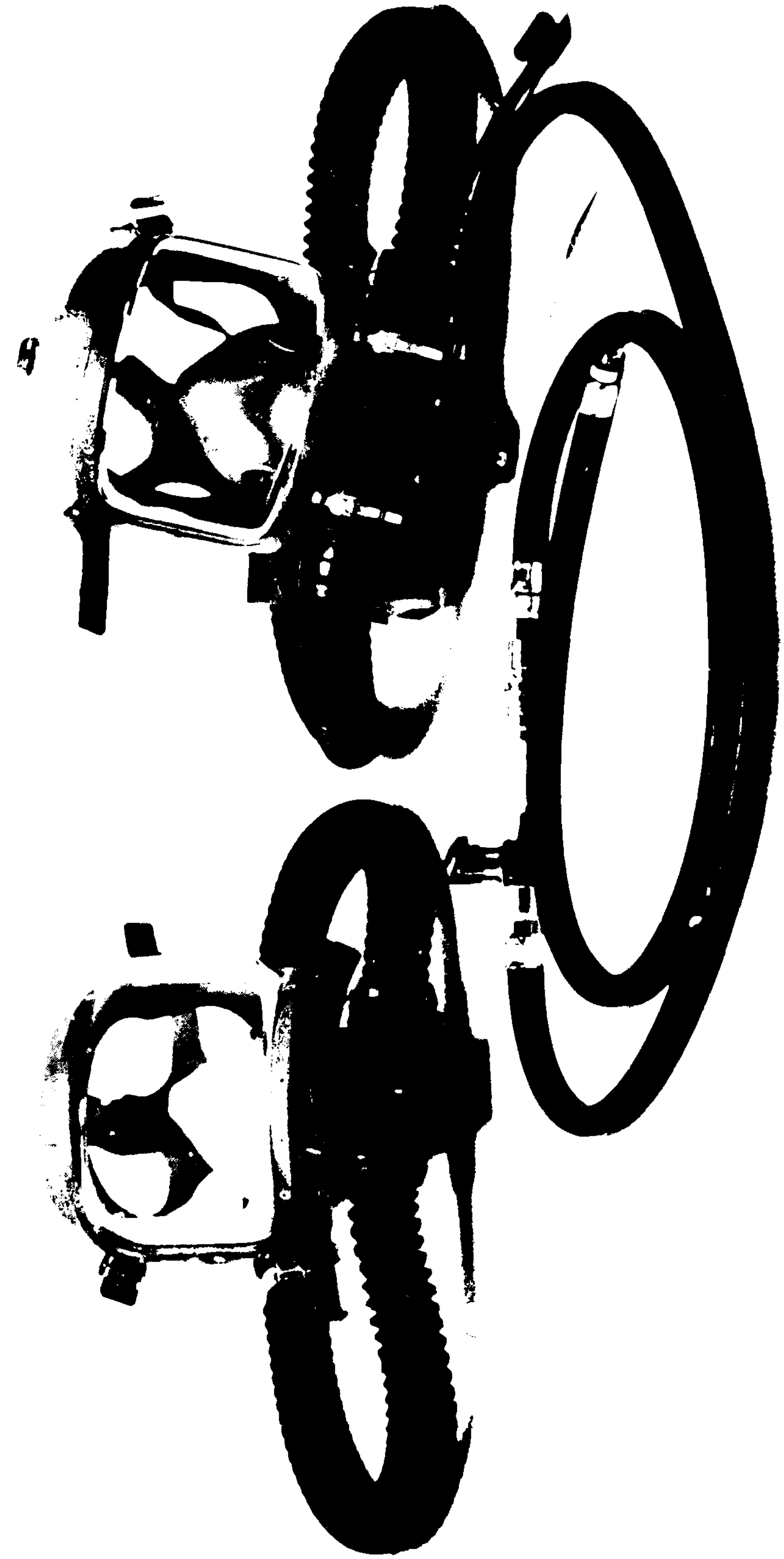

FIGURE 6: MK 15 FFM AND MODIFIED AGA FFM

body as the current MK 15 FFM. This mask can be used with certain MK 16 UBA applications should a requirement be identified, and is suitable for use with both the Draeger LAR V and MK 15 UBAs.

Closed circuit FFM fogging should be the subject of a continued evaluation, as this has proven to be a continued source of complaints. The permanently bonded anti-fog coating applied by Exxene Corp. reduces fogging when a liquid anti-fog is also applied prior to each dive, however this does not totally alleviate the problem. A permanent bond anti-fog coating should be applied to the Interspiro OC1 FFM.

Recommended open circuit flex hose length is 6 feet, with QD fitting located 6 inches upstream of the open circuit regulator. The ¼ turn air supply valve should be located upstream of the QD. Inclusion of the ¼ turn valve in the flex hose assembly is currently recommended.

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